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Safe Parameters for Laser Chondroplasty of the Knee

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Background and Objective: **The purpose of this study is to summarize our use of the Holmium laser as a tool in performing chondroplasties of the knee and to determine whether any untoward affects developed at the site of laser application.**
Study Design/Materials and Methods: **A retrospective review of 504 laser chondroplasties of the medial femoral condyle was done. Laser parameters and the average number of joules to perform the chondroplasties were recorded. The average follow-up was 11 months.**
Results: **Preoperative MRI interpretation indicated that 8% of the patients had osteonecrosis prior to surgery. 88% of the patients were satisfied with the procedure. All failures were evaluated by X-ray, MRI, bone scan, or biopsy of the medial femoral condyle. No new cases of osteonecrosis were determined.**
Conclusion: **No new cases of osteonecrosis were documented of the medial femoral condyle following laser chondroplasty utilizing the parameters in this study. The Holmium laser remains a safe and efficacious tool in performing chondroplasty. Lasers Surg. Med. 23:141–150, 1998.**

INTRODUCTION

The 2.1 μm Holmium:Yag laser has been available since 1989 for use in arthroscopic procedures. This modality has been found to be exceptional in managing chondral surface lesions as a result of its water absorption characteristics. This feature allows this tool to restore unstable and painful lesions to mechanically sound surfaces. There have been many clinical reports in the recent literature regarding the utility and efficacy of laser intervention during arthroscopy [1–12]. Few complications have been directly related to the use of the Holmium laser in arthroscopic surgery [1–6,8–12]. One of the reasons for the low complication rate is the fact that this laser does not penetrate tissues beyond 0.5 mm. (absorption length) [1,2,7,13–15]. Although, thermal damage has been discussed by many investigators as a possible complication, significant thermal damage to adjacent structures has not been reported [7,13–16]. Recently a number of papers have implicated the use of the 2.1 μm Holmium:Yag laser in the development of postoperative osteonecrosis of the femoral and tibial condyles as well as the patella [17–20]. However, very little information was provided by these studies regarding the parameters of laser application at the sites of the development of osteonecrosis. The purpose of this study is to summarize our use of the 2.1 μm Holmium:Yag laser as a tool in performing chondroplasties of the medial femoral condyle in 504 procedures and to determine whether any untoward effects develop at the site of laser application with specific emphasis on osteonecrosis.

METHOD AND MATERIALS

In a retrospective review, from January 1992 through January 1996, 640 knee arthroscopies were performed at our institution; 504 chondroplasties of the medial femoral condyle were performed on 465 patients. The average age of the

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patients was 63.3 years (range 17–89 years). There were 229 males and 236 females. There were 260 right knee arthroscopies and 244 left knee arthroscopies. Preoperative X-rays were obtained of all patients. Weight bearing anteroposterior X-rays were obtained in full extension and approximately 35–40° of flexion. In addition, lateral and patellofemoral views were obtained.

The degree of osteoarthritis was evaluated by Ahlbach's classification [21]: Grade 0, no signs of osteoarthritis; Grade I, narrowing of at least ½ of the joint space; Grade II, joint space obliteration; Grade III, erosions of less than 5 mm; Grade IV, erosion of 5–10 mm; and Grade V, erosions of more than 10 mm. Additionally, the X-rays were evaluated by Lotke's staging for osteonecrosis [22,23]. Stage 1, a normal radiograph; Stage 2, subtle flattening of the involved condyle; Stage 3, a radiolucent area in the subchondral bone bordered by a sclerotic halo; Stage 4, sclerotic halo thickening and subchondral bone collapse; and Stage 5, osseous collapse and associated degenerative changes. Magnetic resonance imaging was performed on 93% of the 465 patients (432 patients). The MRIs were performed with a 0.5 TESLA magnet. All patients had T1 and T2 sagittals, T1 coronals, and fast-field echos (FFE) in the sagittal plane. Section thickness was between 3 and 5 mm.

Diagnosis of osteonecrosis with MRI was based on a pattern of low signal intensity on both T1 and T2 weighted images compared to surrounding bone. The size of osteonecrotic lesions was measured on T1 weighted images using Lotke's method and referred to as a percentage of the diameter of the involved condyle [22,23].

All patients underwent standard arthroscopic surgical procedures using three portals. Tourniquets were applied to the patient's thigh but not used during any of these procedures. Local anesthesia was used in all cases, regardless of whether or not the patient was done under local, general, or epidural anesthesia. All patients had Marcaine with epinephrine instilled intraarticularly. The average surgical time was 50 min (range 35–80 min). The patients were noted to have associated pathology in 90% of the cases. Medial meniscal pathology was noted in 49% of the patients. Chondral lesions were classified according to Outerbridge classification and the classification of Bauer and Jackson [24]. All patients had Outerbridge II or III changes and had Bauer and Jackson II–VI changes. The majority of the lesions were Bauer and Jackson IV, V, and VI. All cartilage lesions of the medial femoral condyle were measured in both the anterior posterior and medial lateral plane to determine the surface area treated. A 22.4 w 2.1 μm Holmium:Yag laser was used in all of our cases. Three power settings were utilized: 10 w (1 joule, 10 hertz), 18 w (1.8 joules, 10 hertz), and 22.4 w (1.4 joules, 16 hertz). Approximately one third of the patients were allocated to each of the laser power groups, namely, 10, 18, and 22.4 w. This was not a random allocation but rather a surgeon's preference. The laser setting was not influenced by the characteristics of the lesions. The number of joules required to perform the medial femoral condylar chondroplasty were recorded. The average number of joules used to perform medial femoral condylar chondroplasty was 3,525 joules (range 200–9,000 joules). The average surface area treated was 300 mm^2 (range 25–800 mm). The technique of chondroplasty was performed by using universally accepted techniques. The procedure emphasized non-contact and tangential delivery of the laser beam. Perpendicular delivery was avoided and the position of the laser probe was dictated by the desired tissue response. Charring of the articular surfaces was avoided in this manner. Postoperatively all patients were allowed to weight-bear as tolerated without an external aid. All patients were entered into a postoperative physical rehabilitation program within 48 hours of the time of surgery. Standard follow-up appointments were 1 day, 1 week, 2 weeks, 6 weeks, and 18 weeks postoperative. These were mandatory and most patients were followed thereafter at three month intervals for a minimum of 1 year. Follow up of these patients averaged eleven months (range 4–36 months). The average follow-up of the failed patients was 23 months (range 10–36 months).

Patient satisfaction was graded on the basis of symptoms and disability [25]: *Excellent,* the patient had no symptoms and no disability related to the knee; *Good,* the patient had minimum symptoms, such as aching or weakness after heavy use or effusion after heavy exertion, but there was essentially no disability; *Fair,* the patient had symptoms, such as trouble kneeling or climbing stairs; weakness, pain, or discomfort had became enough of a problem to interfere somewhat with everyday activities and the patient thought he had some disability; and he was active but could not participate in vigorous physical activities; sedentary employment only; and *Poor,* the symptoms were severe and included all of those listed under fair as well as the presence of

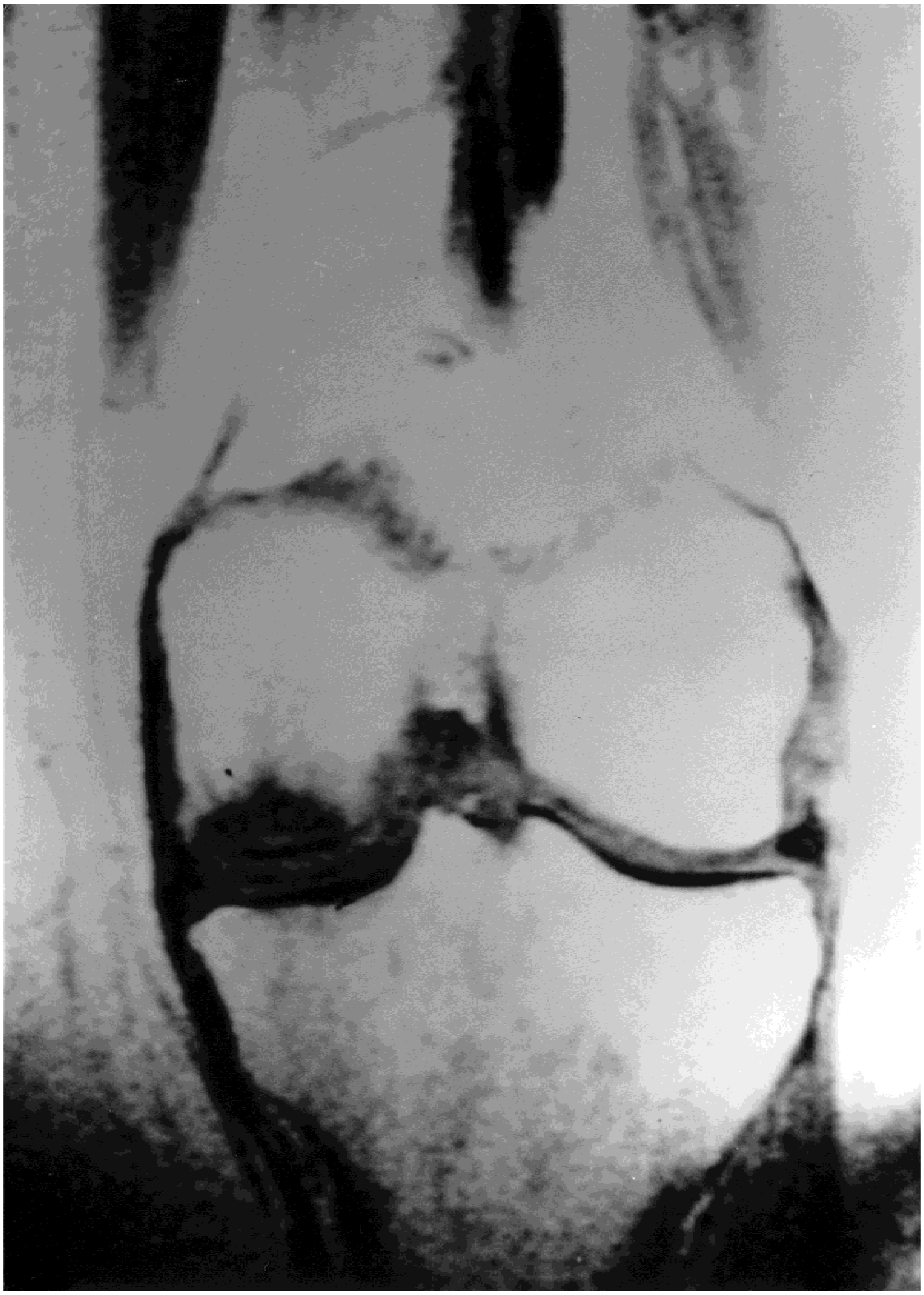

Fig. 1. MRI, coronal section, showing osteonecrosis of the medial femoral condyle.

pain at rest, limited motion, and locking. The patient was clearly disabled, and his activities, including walking, were definitely limited because of his knee and was unable to work.

RESULTS

Preoperative magnetic resonance imaging interpretation indicated that 8% (34 patients) of the patients had osteonecrosis of the medial femoral condyle or tibial condyle prior to surgery (Fig. 1). All but one case in this series were on the medial side. One patient had osteonecrosis of the lateral femoral condyle. When reviewing X-rays of patients with MRI diagnosed osteonecrosis three patients were found to have osteonecrosis on X-ray by Lotke staging (Fig. 2). The remaining X-rays, when an abnormality was noted, were felt to be consistent with early degenerative arthritic changes. The size of the osteonecrotic site using

Fig. 2. Anteroposterior radiograph showing osteonecrosis of the medial femoral condyle.

Lotke's measurement technique ranged from 7–50% of the involved condyle. All patients with preoperative osteonecrosis were excluded from the follow-up. Interestingly, 60% of this group did well and were satisfied with the arthroscopic debridement within the follow-up of this study. The average age of the patients with osteonecrosis was 71 years (61–88 years). The sex distribution was approximately equal. Preoperative X-ray evaluation indicated that 173 knees were categorized as Ahlbach's 0 grading, 216 were Ahlbach's grade I, and 42 were Ahlbach's grade II.

Patient satisfaction following arthroscopic chondroplasty was 88% (380 patients). They were excellent or good by our grading system. Twelve percent (52) of the procedures were considered to be failures and did not improve. The majority of the failures were graded as fair (44). Eight were classified as poor. All of these patients had total joint replacements within 18 months of our pro-

Fig. 3. Medial femoral condylar biopsy from previously lased site showing viable bone and cartilage.

cedure. The patients that fell under the category of satisfactory indicated that they had pain relief that was either complete or partial and required no medications or only non-narcotic analgesics, such as non-steroidal anti-inflammatory drugs. These patients also felt that they had acceptable functional capacities allowing activities to which they were accustomed and they all felt that they had acceptable motion. These patients also had the absence of night pain and if employed, were able to return to their prior work status. There was no statistical difference between the groups when the results of this procedure were correlated with the energy setting of the laser.

Failures were evaluated by one or more of the following: history and physical examination, X-ray, arthroscopic lesion biopsy, biopsy at the time of orthopaedic reconstructive procedure, secondary MRI, or bone scan. No new cases of osteonecrosis of the knee were observed as a direct re-

Fig. 4. **A:** Preoperative MRI showing either changes of osteonecrosis or reactive bone. **B:** MRI 10 months postoperative showing resolution of the osseous changes seen in Figure 4A.

sult of the application of the 2.1 μm Holmium:Yag laser. Of the 52 failures, 34 patients had postoperative biopsies during the course of a secondary arthroscopic procedure or reconstructive procedure; 23 patients had secondary MRI's, and 3 patients had bone scans. The mean time to postoperative biopsy was 8 months. The mean time to postoperative MRI was 6 months.

At the time of our arthroscopic reassessment of our patients the general appearance of the lesion treated by the laser was not substantially changed. There was no change in the classification or size of the lesion, and in no instance was regeneration of articular cartilage noted. The patients who underwent biopsy had viable bone adjacent to the subchondral plate and viable articular cartilage, and in some cases there was evidence of cell replication activity (Fig. 3). The postoperative MRI did not show any significant changes from the preoperative state with the ex-

Fig. 4 continued.

ception of the elimination of preoperative edema noted on the T1 images (Fig. 4A, B). No postoperative X-rays on any of the failure patients suggested Lotke staging of osteonecrosis.

All failures were associated with medial femoral condyle chondral lesions greater than 200 mm^2 (range 200–520 mm). All failures were classified as either Ahlbach's Grade III or IV. Forty-three of the fifty-two failures were associated with medial meniscal pathology. The predominant tear pattern was mid to posterior. There were no bucket-handle tears in this group.

The following complications were noted in this series: One patient developed deep venous thrombosis, which was localized to the calf and was treated successfully with anti-coagulant medications. One patient developed postoperative lymphedema of unknown etiology and was man-

aged medically with slow resolution of this problem. Two patients developed symptomatic postoperative popliteal cysts. One of these resolved and one required popliteal cyst excision. Four patients developed postoperative arthroscopic synovitis which resolved between 3 and 6 months post-op. None of these patients had a positive culture on arthrocentesis. All had elevated sedimentation rate which returned to normal. One patient developed a postoperative ganglion of the anterolateral portal. This resolved spontaneously. Ten patients developed drainage from one of the three standard arthroscopic portals that lasted greater than 2 weeks. All of these resolved spontaneously. The only complication directly associated with laser use in this series was one broken fiber with a minor burn to the operating surgeon's hand and one arthroscope lens was cracked because of the misfiring of a cracked laser fiber.

DISCUSSION

Holmium is a rare earth element that when combined with a yttrium, aluminum, and garnet crystal emits a laser beam in the near infrared range at a wave length of 2.1 μm. When the Holmium laser is pulsed this high energy laser causes minimal thermal damage to tissue. This is due to the tissue cooling between individual pulses and also the shallow depth of penetration of this wave length (approximately 0.4–0.6 μm). Although rapidly absorbed by water within tissue the Holmium laser can be affectively utilized in an aqueous medium. This medium also lessens the thermal damage by its inherent cooling effect. By varying the pulse repetition rate (hertz) and energy level (joules) different tissue affects, such as cutting, coagulation, and/or ablation can be obtained. The Holmium laser beam can be delivered fiberoptically through a flexible silica quartz fiber set in a variety of angled hand pieces. Since this laser beam can be delivered in an aqueous medium it is an ideal tool for use in arthroscopy [1–4,6,8, 11,12].

The Holmium laser has many theoretical and practical advantages over other laser wave lengths and conventional mechanical or motorized instruments. The laser does the work of many tools; cutting, coagulating, nerve end welding, vaporizing, tissue tightening, and sculpting. The hand pieces are small minimizing damage to articular surfaces and providing access to difficult to reach areas. The Holmium laser is very safe. The laser beam travels only 2–3 mm past the tip of the quartz fiber when used in an aqueous medium. The tissue depth of penetration is very shallow. There is minimal lateral or adjacent tissue destruction and essentially no charring is noted with use of the Holmium laser.

The Holmium laser is especially useful for chondroplasty. It provides mechanically sound surfaces because of its superior tissue smoothing capabilities and is much less damaging as compared to motorized shavers. This theoretical advantage has been substantiated in clinical studies [3,4,8,10,11]. The safety of the Holmium laser has been supported by hundred of thousands of clinical uses. Multiple investigators have dispelled concerns about thermal damage when properly utilized [1,3,4,6,7,9,13,14]. Consequently there have been very few reports of complications directly related to the tissue effects of this laser. Complications that have been reported, such as fiber or arthroscopic damage, did not result in any injury to the adjacent tissues [1,2]. In this study the failed patients were attributed to the extent of the disease process within the involved knee and not to the laser effect. Our extensive follow-up with these patients showed no undo progress of their disease and no significant changes as seen on x-ray, MRI, biopsy, or direct inspection.

Recent studies have implicated the Holmium laser in the development of postoperative osteonecrosis [17–20]. These studies were poorly documented. They did not provide information regarding the site of laser application, the size or classification of the lesion, the energy parameters used, the total energy applied, or the time of application or the method of application. No comments regarding misuse of the laser were made and most cases did not have preoperative MRI documentation. These papers also ignored the fact that spontaneous osteonecrosis is multifactorial. The condition was first described in 1968 by Ahlbach and can occur in the femoral or tibial condyles as well as the patella [21]. The etiology is still debated. Osteonecrosis can be primary or secondary. The latter has been associated with alcoholism, corticosteroid use, hyperbarism, hemoglobinopathy, meniscal pathology, as well as arthroscopic meniscectomy [21,22,26–30]. Interestingly, the association with meniscal lesions and with arthroscopic meniscectomy was not given much emphasis in these reports. Drucker recently reported on the development of osteonecrosis of the knee following conventional and laser assisted arthroscopy and found no statistical difference in incidence [31].

In the articles implicating the Holmium la-

ser in the development of osteonecrosis three etiologies were proposed: thermal, pressure and inflammation, or photoacoustic shock. The thermal hypothesis was dispelled by Garino [18] in his report based on known physics of the Holmium laser and previous basic science data [7,13–15]. The pressure/inflammation theory would be discounted by many of the same arguments against thermal damage. This present study showed no evidence of either of these factors in our failed patients based on direct inspection, histologic review of biopsied specimens, and postoperative MRI.

The photoacoustic shock hypothesis is presently receiving a great deal of attention in ongoing studies. Essentially the photoacoustic shock characteristics closely mimic those of thermal delivery with little likelihood of significant subchondral bone transfer as long as the laser is utilized in a non-contact mode. The laser parameters utilized within this study did not demonstrate any damage attributable to such a mechanism. The surgical method of laser assisted chondroplasty emphasized in this study would minimize any significant photoacoustic affect, that is, a non-contact mode and tangential delivery of the laser beam. Fink [17] in his report of two cases of cartilage sloughing with osteonecrosis following laser assisted surgery conceded that the photothermal affect of the Holmium laser is less than other lasers but then confused the issue by citing data that implicated the laser in causing significant thermal damage. The references that he used to come to these conclusions were studies using lasers other than the Holmium, or the Holmium used in non-clinical settings using perpendicular and contact modes of delivery of laser energy. He also exaggerated the depths of cellular response.

Based on the information in the literature and the findings in this study we feel that the 2.1 μm Holmium:Yag laser is a safe, simple and efficacious tool. The likelihood of laser induced complications are minimal if used judiciously. The parameters used in this study are just guidelines but apparently are safe. Most experienced laser surgeons suggest 1 joule of energy or less for chondroplasty with a rapid repetition rate. The actual energy or fluence (joules per mm^2) delivered to the tissue is much less than the setting of the laser. This is based on the fact that the energy rapidly dissipates as the distance from the tip of the fiber increases. There is also a divergence of the laser beam which increases the spot size, and tangential delivery also increases the spot size. Energy is also dissipated by the creation of the Moses effect. The incidence of osteonecrosis should be no greater when performing laser assisted chondroplasty as compared to mechanical chondroplasty, assuming proper application, but this awaits a randomized prospective study to put an end to this controversy.

At this juncture the Holmium laser remains a well-designed tool for chondroplasty of the medial femoral condyle selectively ablating and smoothing diseased articular cartilage with much less damage than that of mechanical tools used for the same purpose.

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